



NDE Software Developed at NASA Glenn Research Center

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Abstract

NASA Glenn Research Center has developed several important Nondestructive Evaluation (NDE) related software packages for different projects in the last 10 years. Three of the software packages have been created with commercial-grade user interfaces and are available to United States entities for download on the NASA Technology Transfer and Partnership Office server (<https://sr.grc.nasa.gov/>). This article provides brief overviews of the software packages.

Introduction

NASA Glenn Research Center has developed several important Nondestructive Evaluation (NDE) related software packages for different projects in the last 10 years. Generally, custom software is required as no one commercial package is able to address project requirements for the wide variety of NASA's research programs. It seems a wasted effort to develop the software and have only limited potential use of it, especially with United States taxpayers footing the bill. Therefore the lead author tends to approach software design with an eye towards eventual use of the software outside of NASA. It then becomes critical to plan the software so that it can be easily maintained and upgraded by the authors even years later. Also, the usability aspect needs to be taken very seriously so outside users can employ the software with reasonable effort. Thus, the underlying code and user interface are developed with these issues considered.

Three pieces of software have been developed using commercial-grade software interfaces and converted into executables. With executables, the user is not required to perform any software programming. Installers for these executables are available to United States entities for download at NASA's Technology Transfer and Partnership Office server (<https://sr.grc.nasa.gov/>). The installer packages include a detailed user manual with complete installation instructions and a quick start guide. This article provides descriptions of these software packages which include NDE Wave & Image Processor (NDEWIP), Cylinder Unwrapper/Reslicer Software (CT-CURS) for Computed Tomography (CT), and Acoustic Emission Analysis Applet (AEAA).

Software Program 1: NDE Wave and Image Processor

Ultrasonic, microwave, terahertz, and radar Nondestructive Evaluation (NDE) imaging systems generally require the acquisition of waveforms at each scan point to form an image. Acoustic emission, ultrasonic guided wave, and vibration data might require modal analysis after waveform acquisition as well. Other NDE methods such as digital X-ray, X-ray computed tomography, shearography, acoustography and thermography use detector arrays or other means to capture full-field image data. In many cases, it can be quite useful to supplement signal and image processing and analysis products from NDE equipment whose vendor-supplied software lacks anything more than basic functionality. An integrated, upgradable facility in which all visualization, processing, and analysis at the state-of-the-art level is quite desirable. We have created and describe here, just such a platform.

The *NDE Wave & Image Processor (NDEWIP)* software application was created to provide a comprehensive, interactive, state-of-the-art, integrated software tool for advanced visualization, processing, and analysis of all types of NDE and Health Monitoring waveform- and image-based data (Ref. 1). Once a data set is imported into the software, advanced visualization, processing, and analysis can be accomplished all in one facility, in one run, and independent of vendor software resident on particular equipment. Although the software is focused on the NDE applications, there is nothing to prevent it from being used for any other RF signal or image processing and analysis application. The capabilities are provided through a user-friendly, interactive, graphical user interface. This software can be useful for cross-organization projects requiring a common platform from which to visualize, process, and analyze data. For team leads, this means simplified processing and analysis of all data types without the use of multiple tools or formats.

This software can also be used for educational purposes to train staff and students in the areas of signal and image processing and analysis. In fact, it has been used as the basis of a course taught in this field and to jump start NASA staff, particularly new employees, in this area. Perhaps the most valuable use of this software is as a rapid prototyping tool for processing and analysis procedures. Even if a user's preferred software processing environment is for example, MATLAB (The Mathworks, Inc.), the use of NDEWIP can rapidly provide information on a variety of procedures and algorithms that might be optimal for the user's data without the need for software programming.

NDEWIP was designed to handle data sets on the order of 200 MB for the 32-bit version (and 1 GB for the 64-bit version). Batch processing capability included in the software provides a workaround for the data set size limitation. The basic handling of user actions is performed using event-driven state machine architecture as described in Appendix A.

NDEWIP features and capabilities include:

Signal Processing

- Gating (including static, peak-tracking, sliding, and multiple), focusing on temporal location, used to focus on time-area of interest on waveform and apply processing to that location. Greatly reduces processing time versus applying processing to entire wave if using digital filtering, wavelet denoising, etc.
- Extraction of a wide variety of features from waveforms in time-domain (amplitude- and time-based) and in frequency-domain (magnitude- and phase-based).
- Waveform Pre-processing.
 - Digital filtering (Infinite Impulse Response, Finite Impulse Response, and Smoothing Filters).
 - Wavelet denoising, detrending, and multiresolution analysis and reconstruction.
 - Gated pre-processing versus entire waveform pre-processing.
- Deconvolution (with instrument response function: Time-Domain Subtraction, Inverse Filter, Weiner, Iterative Weiner, Richardson-Lucy).
- Density-Thickness processing to allow material dimensional and microstructural assessment (for example with microwave, terahertz, or ultrasonic data).

Signal Analysis

- Peak-Detection.
- Model-based Curve Fitting.
- Joint Time-Frequency Analysis with Dispersion Curve Overlay.

Image Processing

- Normalization.
- Binarization/Binary Thresholding.
- Grayscale balance (brightness, contrast, gamma).
- Custom color table creation and multi-thresholding of data regions.
- Cropping.
- Resampling.
- Range-based Lookup Table Transformations (contrast expansion, exponential, logarithmic).
- Outlier removal (masking of extreme values and removal for statistical analysis purposes).
- Image histogram equalization.
- Three-dimensional surface graph representations of images.
- Orientation modifications (flip, mirror, transpose, rotate).
- Edge extraction (several different varieties including wavelet-based and Canny).
- Smoothing Filters.
- Detail Enhancement.
- Binary Morphological Operations (fill holes, remove border, dilations, erosions, segmentation, shape filtering, etc.).
- Deconvolution (with point spread function: Inverse Filter, Weiner, Iterative Weiner, Richardson-Lucy).
- FFT filter (low-pass, high-pass, band-pass, band-stop image filtering).
- Two-dimensional wavelet denoising.
- Two-dimensional wavelet decompositions and reconstructions (effectively a very powerful multi-level band-pass image filtering method).
- Custom linear filter module including user-defined or pre-built gradient, laplacian, gaussian, and other kernels. Very powerful for directional filtering to determine preferred orientations of phases or features.
- Multi-surface Rendering of Image Series (such as for X-ray Computed Tomography or to visualize a Thermography time series).
- Manual and Automated Multi-region thresholding.

Image Analysis

- B-scan time and depth display and analysis.
- Addition, subtraction, division, scaling, fusion, and comparison of images.
- Image averaging of a Series of Images. Principle component analysis (PCA for a series of images).
- Region of interest (ROI) processing and means testing.
- Line profile and feature measurement.
- Areal fraction measurements.
- Particle (flaw) Analysis measurements (diameter, perimeter, area, elongation, etc.).
- Differentiation for series of images (1st, 2nd, and 3rd derivative images can many times highlight information not available in raw frames as has been shown in thermography).
- Sectional Analysis for image series data cube.

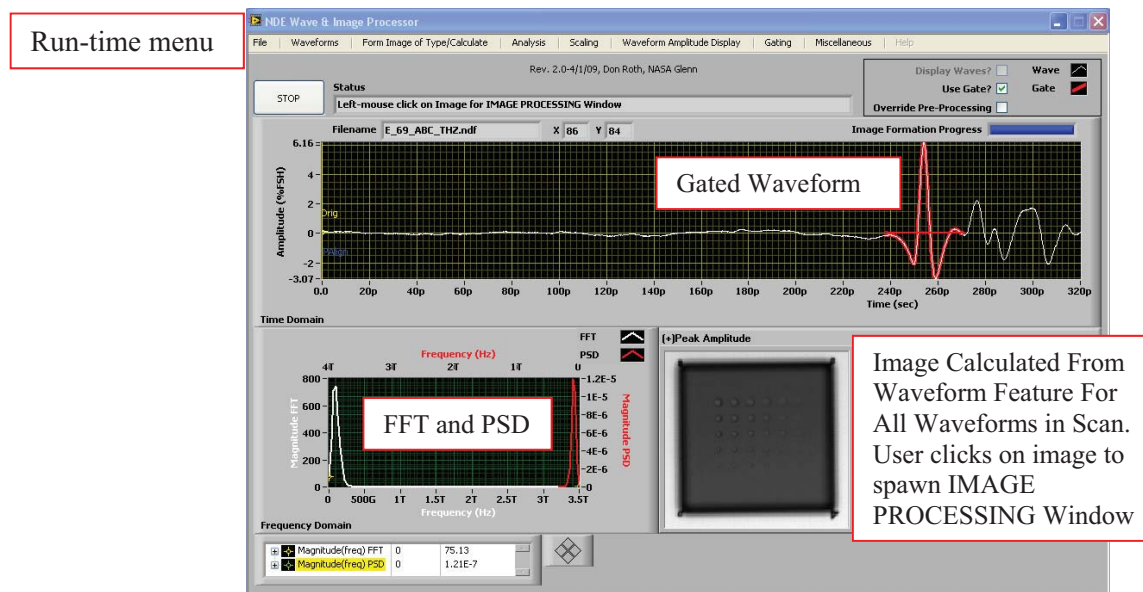
Scripting and Batch Processing

- Interactive determination of a best set of signal processing actions for one waveform and apply to entire folder of waveforms.
- Interactive determination of parameter estimates for a best nonlinear curve fit for spectra data and apply parameter estimates to an entire folder of spectra.
- Interactive determination of a best set of image processing actions for one image and apply to an entire folder of images. Batch analysis is also provided for areal analysis of an entire folder of images.

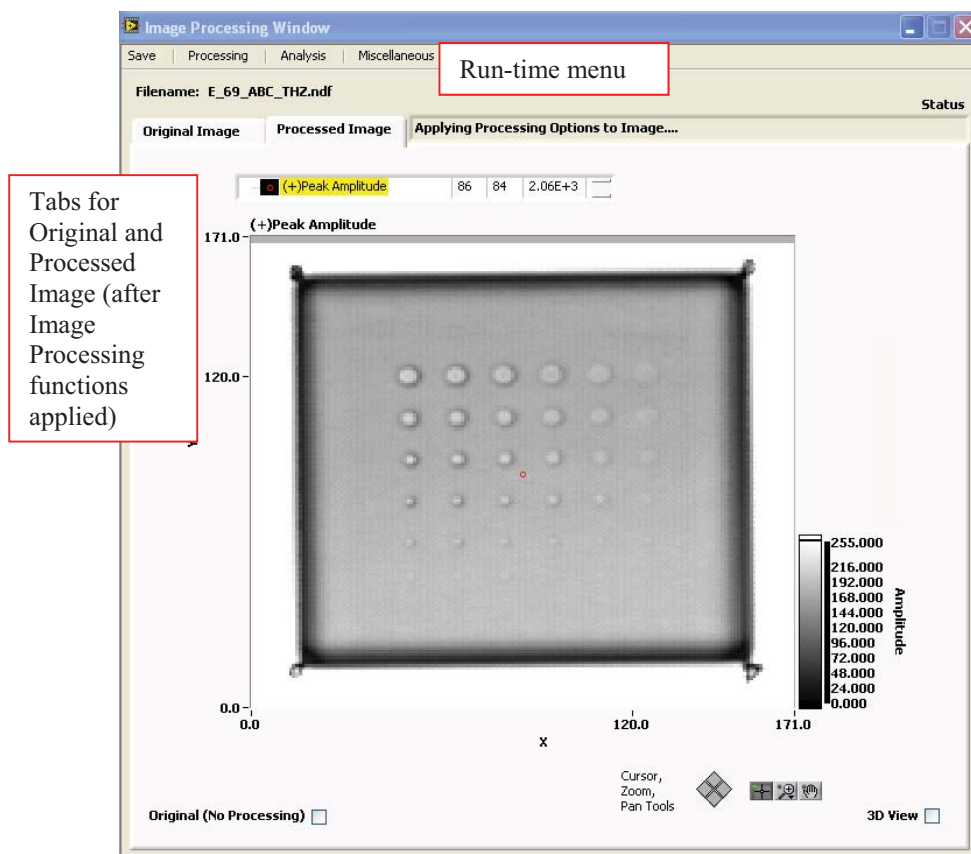
Data formats that can be opened include:

- **Waveform Files:** These files may be of type NDF or Raw (byte) file, both described below.
 - *NDF Format:* Currently at NASA GRC, Terahertz, UTEX ultrasonic c-scan, and Ultrasonic Guided Wave Scan waveform data are stored in a binary format (.NDF) originally used at NASA Langley Research Center (LaRC) for terahertz data acquisition. It is suggested that users store their waveform-based NDE data in this format so it is described in detail in Table 1 of Appendix B so that scientists and engineers may format their data for use with the *NDE Wave & Image Processor* software.
 - *Raw (Byte File) Format:* Waveform files of this format have a known length (or no) header followed by a sequential ‘stack’ of waveforms. More information on required input for this format is given in the user manual.
- **Image Files:** These files may be of type .png, .bmp, .jpg, .tiff, .txt (ASCII raw data text file openable in Microsoft Excel), .bin (a 2d raw data file of single-precision floating point numbers), .rec, .att, .liv, .raw, (the latter four types are Hytek Xray CT file types), .XP (GRC SMS Xray CT file). Additionally, Image Series may be in .avi format or straight binary (.raw format not to be confused with Hytek .raw file type). More information is provided for opening image and image series files in the user manual.
- **ASCII X-Y Files:** The data file, if opened in Notepad, should be two columns of *tab-delimited* data (column 1 is X data [ascending order], column 2 is Y data) or one column of Y data. More information is provided for opening ASCII X-Y files in the user manual.

Figure 1 shows screen shots of the MAIN WAVEFORM and IMAGE PROCESSING window in NDEWIP. There are a great number of other windows and dialogs that are used in NDEWIP.



(a)



(b)

Figure 1.—NDEWIP main interface windows. (a) Main waveform window. (b) Image processing window.

System Requirements to install and run NDEWIP executable include:

- Personal computer (PC) with Windows XP or Windows 7.
- 1 GHz or faster processor.
- 1 GB RAM or more (data files on order of 100 MB) (2 GB or more needed for raw data files 400 MB and larger). It is recommended to keep data files < 250 MB as some users have reported ‘out of memory’ errors with larger data sets.
- 1 GB of available hard-disk space for installation including sample data sets to test.
- Reasonably good video graphic capability so that gate draws and drags are smooth.
- Some temporary files can be created during certain processes so hard drive space should have minimum of 1 GB free as an estimate. The temporary files are destroyed at each run.
- Display screen of 19 in. minimum is recommended. The program can be used on smaller laptop screens but the various windows will need to be repositioned manually more often since less screen space is available.
- National Instruments LabVIEW 2010 32-bit run-time engine (RTE). Included with Installer. (A 64-bit installer is available upon request that would enable some increase in file size processing.)
- Although NASA does not require a paid license to use the software, National Instruments Vision RTE License (~\$300 one-time lifetime license cost) is required due to the use of Vision functions. 32-bit Vision RTE license is needed. (64-bit Vision RTE license is needed for 64-bit NDEWIP.) The product can be used in evaluation mode for free for 30 days without activation. To use beyond 30 days, a Vision run-time lifetime license serial# can be purchased from National Instruments ((888) 280–7645).

A summary description of NDEWIP is available at:

http://www.grc.nasa.gov/WWW/OptInstr/NDE_Wave_Image_ProcessorLab.html and the software can be downloaded at <https://sr.grc.nasa.gov/public/project/76/>.

Software Program 2: Cylinder Unwrapper Reslicer Software for Computed Tomography Results (CT-CURS)

Computed Tomography (CT) data visualization in cylindrical structures, especially those with very thin walls, presents an immense challenge from the human factors standpoint. Extensive zooming and panning is required when viewing each slice (Fig. 2) which is impractical for timely inspection. Additionally, the inner wall can be ill-defined at the low voltage settings when contrast needs to be optimal (Ref. 2). Since high resolution detectors are capable of generating thousands of slices, analysis using top view slices alone is simply impractical. When analyzing volume renderings, grayscale, texture and contrast expansion schemes have to be constantly adjusted and rendering artifacts are common. Thus, it is difficult to separate flaw from graphic anomalies in the volume renderings.

In general for flaw detection in cylindrical CT data sets, it can be advantageous to unwrap the 360° data so as to view 2-D “sheets”. The data is resliced from the exterior to interior of the cylinder where the distance between slices is the voxel dimension. In this section we describe the *Cylinder Unwrapper Reslicer Software for Computed Tomography (CT-CURS)* (Ref. 3) developed at NASA Glenn Research Center to aid in analysis of CT data from ultra-thin wall cylindrical super alloy pressure vessels in the Advanced Stirling Radioisotope Generator (ASRG) program (Ref. 2).

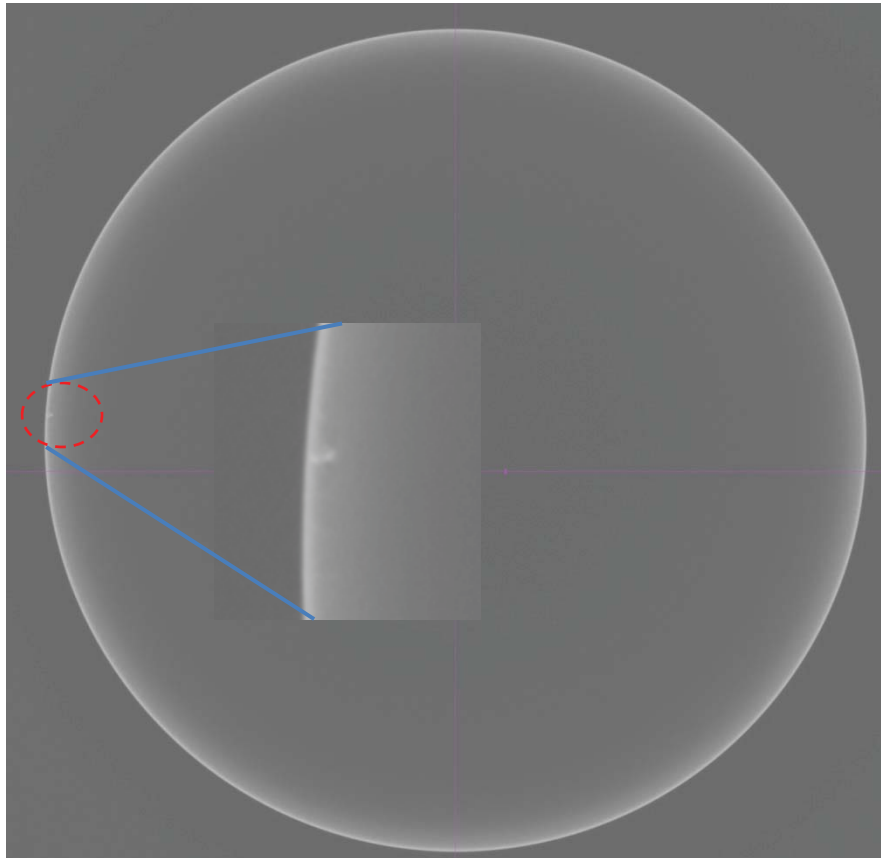


Figure 2.—Top view CT slice of cylindrical structure showing the thin, ill-defined inner wall, and exploded view of an actual flaw found. This image illustrates the difficulty of inspecting top view CT slices for flaws.

The basic methodology to perform unwrapping and reslicing with CT-CURS is illustrated in Figure 3.

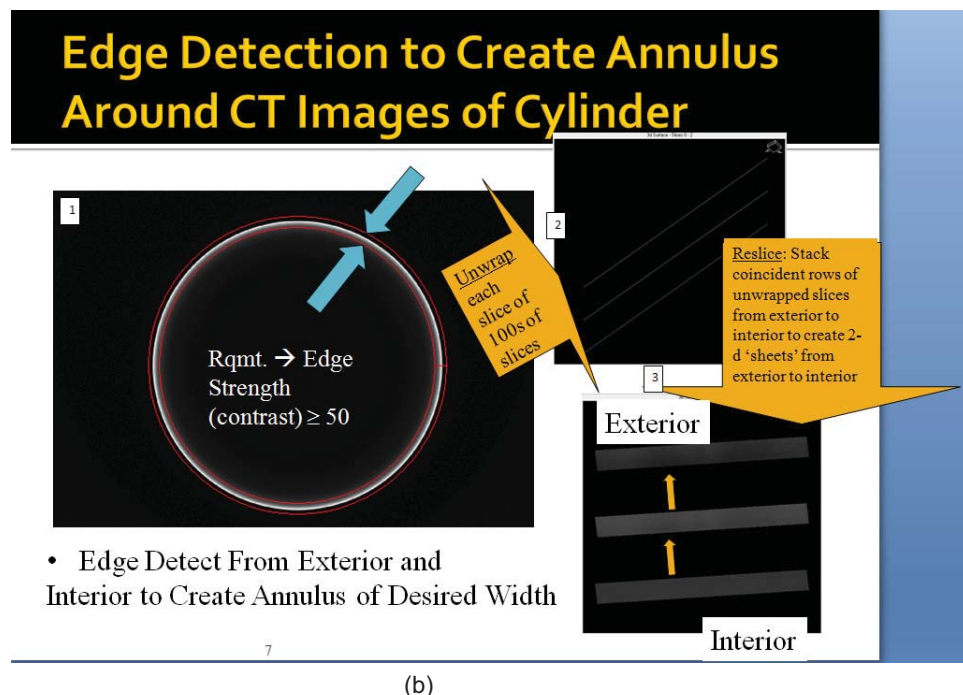
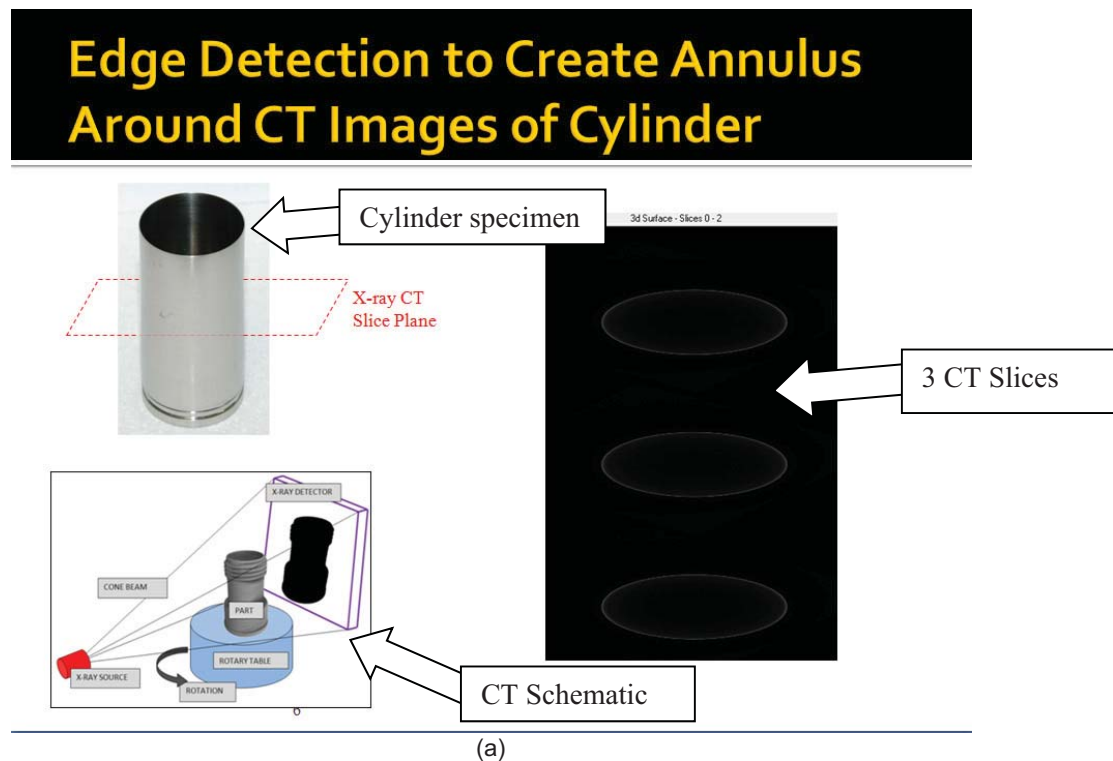


Figure 3.—Methodology used for unwrapping and reslicing cylindrical CT data in CT-CURS. (a) Cylinder specimen, CT schematic, and a 3-D view of 3 CT slices out of hundreds or thousands that might be obtained. (b) Edge detection of cylinder wall, unwrapping, and reslicing strategy.

The basic strategy for unwrapping and reslicing the CT slice images is as follows. An annulus is defined that is positioned using automated edge detection to surround the XY CT slice. The width of the annulus along with the voxel dimension from the CT scan defines the number of 2-D sheets that will be created from exterior to interior. Each CT slice of the cylinder is unwrapped to “linearize” the 360° slice. The linearized slices at each vertical location are stacked to create a data cube. Then, the data cube at every pixel location of the cylinder from exterior to interior (in the radial direction) is sliced to create the 2-D sheets. The increment in going from the exterior to the interior is the CT voxel dimension from the experimental conditions of the CT scan. The number of 2-D sheets = [Annulus width (mm)/voxel dimension (mm)] + 1.

The following details some of the features and advantages for the user of CT-CURS.

- **Ease of Use:** The unwrapping method is FULLY AUTOMATED requiring no input from the user except proper voxel dimension and edge strength (contrast between edge and background gray level intensities) from the CT experiment and wall thickness of the part. The cylindrical part can have a non-constant wall thickness from top to bottom.
- **Precise Results:** An automated slice alignment algorithm with sub-voxel resolution is included which assures optimal unwrapping results. As the reslices are located further into the wall of the cylinder, the diameter and circumference are reduced and this is taken into account through calculation of a reduced “effective voxel dimension.”
- **Inspection Facilitation:** Visualization of the data is possible in a reasonably small number of views (moving from exterior to interior) without having to rotate and adjust transparency and color for a volume rendering or without having to cycle through hundreds or thousands of top view slices.
- **Optimal Visualization of Flaws and Other Outlier Features on Thin Wall Cylindrical CT Data:** Flaw detection on top view slices for a cylindrical component with very thin walls and/or ill-defined interior wall due to x-ray scatter is extremely difficult. However, for unwrapped reslices, if using local contrast expansion option provided in this software, the flaws “pop out” at inspector and are much more easily visualized.
- **Visual Cues:** The location of the unwrapped reslices within the interior of the cylindrical part are shown on the top view slices in real-time via a circle indicator as the inspector cycles through the reslices. THIS VISUAL CUE IS NOT AVAILABLE IN ANY COMMERCIAL CT VISUALIZATION SOFTWARE AND IS EXTREMELY IMPORTANT FOR THE INSPECTOR TO UNDERSTAND THE INTERIOR LOCATION OF THE FLAW IN THE COMPONENT.
- **Quickly Find Flaws/Features in Top View Slices:** Clicking on a flaw/feature in the unwrapped resliced view recalls the proper top view slice and draws a line from the center of the top view slice to the exact angular/polar location of the flaw on the top view slice. THIS ANALYSIS CAPABILITY IS NOT AVAILABLE IN ANY COMMERCIAL CT VISUALIZATION SOFTWARE AND RESULTS IN MASSIVE TIME SAVINGS FOR THE INSPECTOR HAVING TO FIND AND CHARACTERIZE FLAWS.
- **Accurate Lateral Dimensional Analysis:** Accurate lateral dimensional analysis of flaw dimensions is only possible on unwrapped reslices. This software provides a suite of tools for image processing and analysis to allow sub-voxel flaw dimensional analysis. One of the analysis tools is a circular gauge tool that can be set at any diameter to screen for critical flaws of specific size.
- **Easily Save, Reload, and Animate Reslice Sets:** Avoid lengthy re-processing by saving the unwrapped reslice sets for analysis at future times.
- **Unlimited Size Data Sets:** CT data sets may be on the order of 10 GB or larger.
- **Integration with AVIZO:** For extensive further visualization, image processing and analysis, this software is integrated with the acclaimed VSG AVIZO Fire v7 software in order to allow orthoviews and volume rendering of the CT data. (An AVIZO license is required and must be purchased.)

Figure 4 shows the MAIN User Interface for CT-CURS. The options are discussed in detail in the manual. The user needs to input the voxel dimension from the scan, a desired annulus width (or use the mouse to adjust the annulus on the top view shown in the image indicator), and adjust edge strength (contrast between wall indication and background) so that annulus surrounds the cylinder wall properly. Other options that can be selected include alignment method (advanced options available when edge detection is not effective for detecting cylinder OD), annulus method (how the annulus will be positioned), contrast expansion, and image saving.

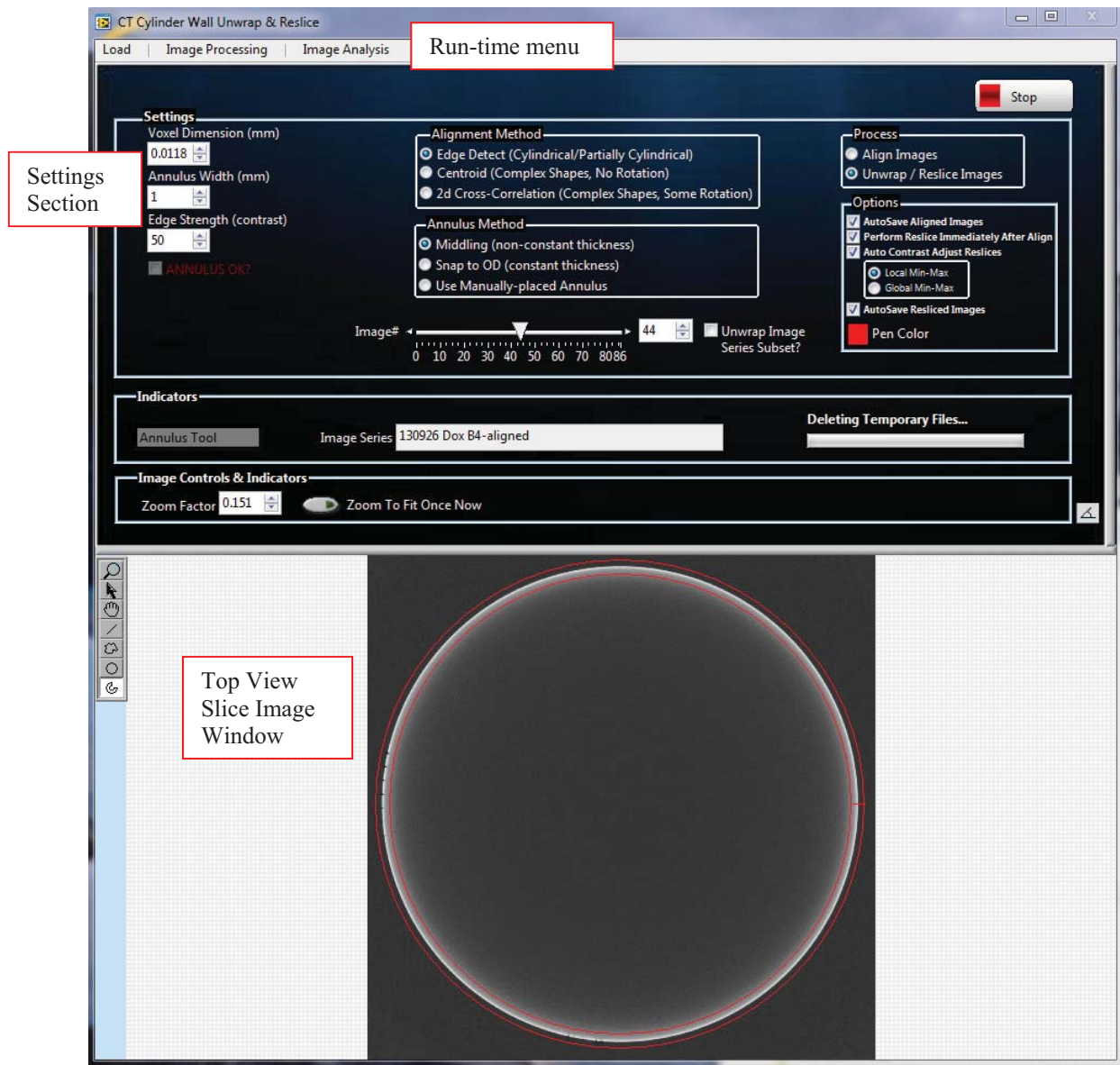


Figure 4.—MAIN interface window for CT-CURS.

Figure 5 shows the unwrap/reslice window that spawns after the procedure has completed.

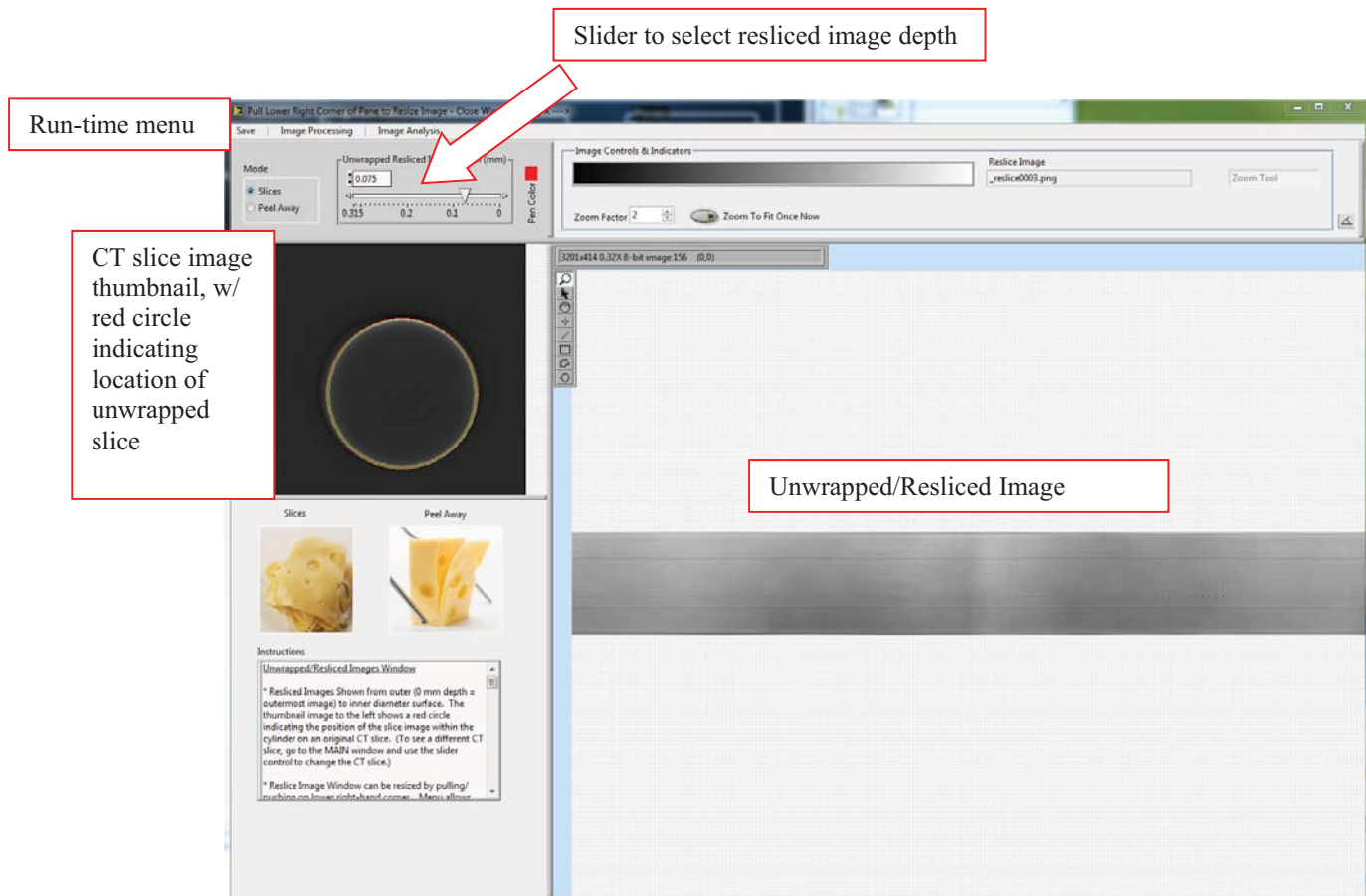


Figure 5.—Unwrapped/resliced images window.

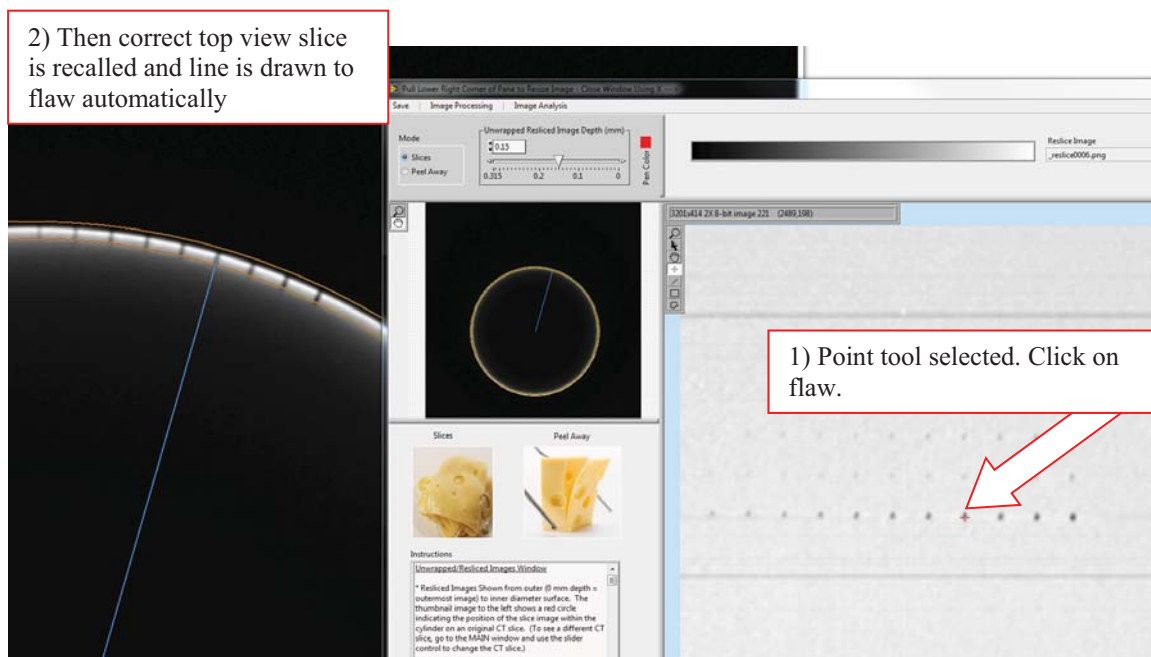


Figure 6.—Example of the ability to quickly find flaws/features in top view slices by locating them first in unwrapped/resliced image.

Figure 6 indicates an important element of this software—the ability to locate features on top view slices by pointing and clicking with the mouse on features in the unwrapped/reslices.

System Requirements to install and run CT-CURS executable include:

- PC running Win7 64-bit OS (version is available also for Win7 32-bit OS).
- 1 GHz or faster processor.
- 4 GB RAM.
- Minimum 100 GB Hard Drive Space but will depend on typical CT data file size processed.
- National Instruments LabVIEW 2011 64-bit run-time engine (RTE). Included with Installer.
- National Instruments Vision Toolkit Run-Time License.

A Summary description of CT-CURS is available at:

http://www.grc.nasa.gov/WWW/OptInstr/NDE_CT_CylinderUnwrapper.html. The software is downloadable at <https://sr.grc.nasa.gov/public/project/86/>.

Software Program 3: Acoustic Emission Analysis Applet (AEAA)

An *acoustic emission (AE) analysis software applet (AEAA)* has been developed that allows analysis of acoustic emission data with some specific capabilities tailored for composite pressure vessels. The applet currently can import Physical Acoustics, Inc. (MISTRAS Group) and Digital Wave, Inc. data. The software was developed to help analyze acoustic emission data during pressurized testing of composite overwrap pressure vessels (COPV) that are critical to NASA spaceflight operations (Ref. 4). The applet provides advanced analysis capabilities and features such as

- Creation of a condensed file from multi-channel data using the data from the channel that experiences first arrival of waveform data (first hit data).
- Event waveform recall.
- Digital and Wavelet Filtering for Event Waveforms.
- Waveform Thresholding.
- Waveform Subsetting.
- Calculation and display of many different AE statistics versus Time and Pressure.
- Breakpoint analysis.
- Event filtering based on amplitude, duration, pre-trigger energy, pre/post energy ratio.
- FFT analysis.
- Partial Powers Analysis.
- Joint-Time Frequency Analysis.
- Imported data converted to NDF format (Appendix B).
- Unlimited Data Set Size.
- Highly interactive mouse and cursor-based user interface.
- Translators can be written for any defined data format to convert to the NDF format required to use the software (NDF format spec supplied in Appendix B and in user manual).

As listed above, the software includes some unique event filtering and data analysis methodologies. Although the current applet is post-processing software, the software can be a model for structural health monitoring during vessel operation where statistics versus time can be updated in near real-time.

Figure 7 shows the MAIN window for AEAA.

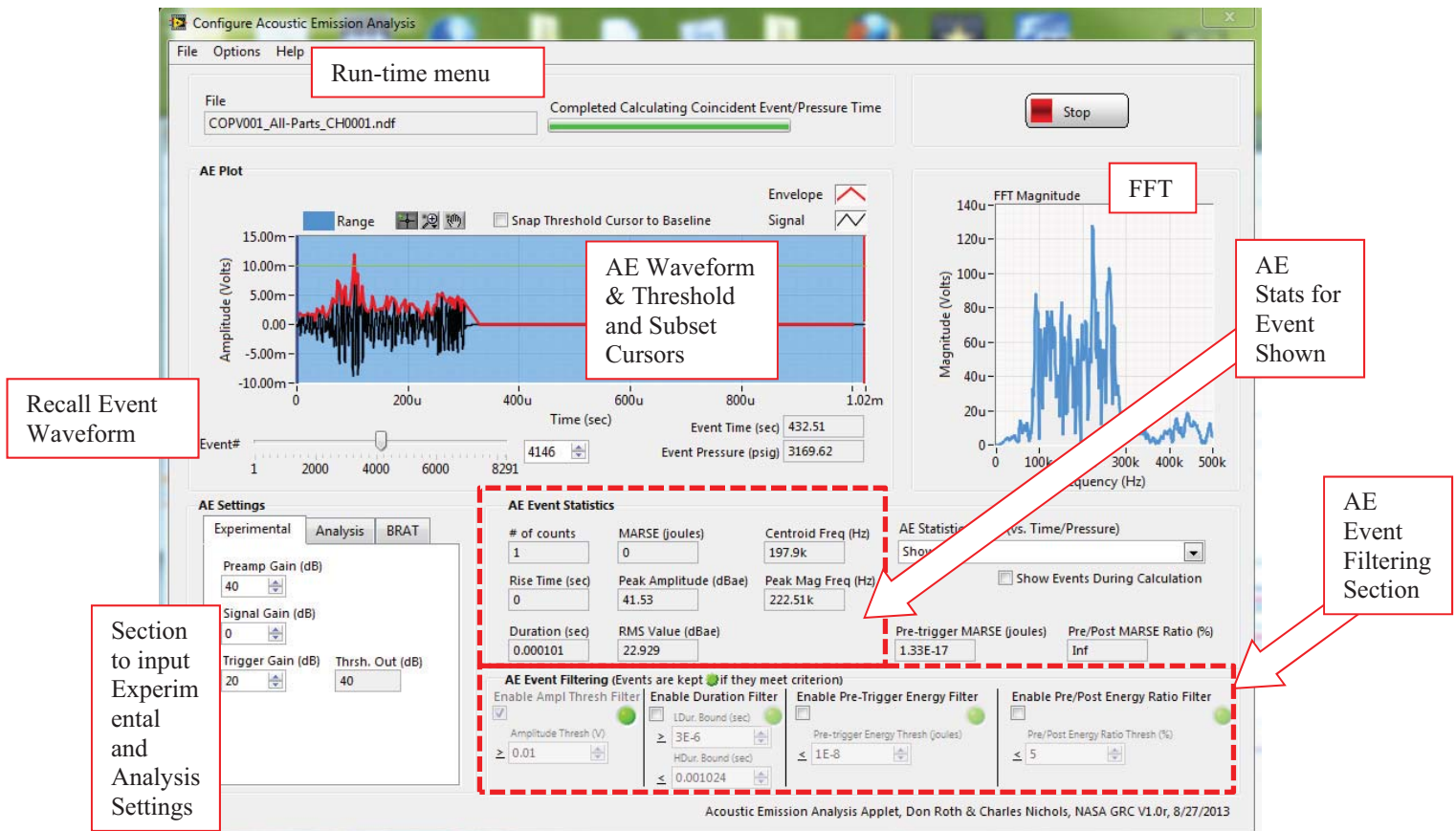


Figure 7.—MAIN window for AEAA after opening data file.

Figure 8 shows the AE statistics versus time and pressure window. The pressure ramp is shown in synchronization with AE statistics. AE statistics include counts, rise time, duration, energy, peak amplitude, RMS, Event# versus time, frequency versus time, energy versus frequency, and partial power fraction versus time and frequency.

Partial Powers Analysis, allows a fractional analysis of power within different frequency bands. The calculation of partial powers with frequency bands has been shown to change over time and correlate with dominance of different mechanical damage mechanisms for composite vessels as shown in Figure 9. The calculation is performed by adding the square of the magnitude values within each frequency band, and dividing by the square of the magnitude values over the entire frequency band.

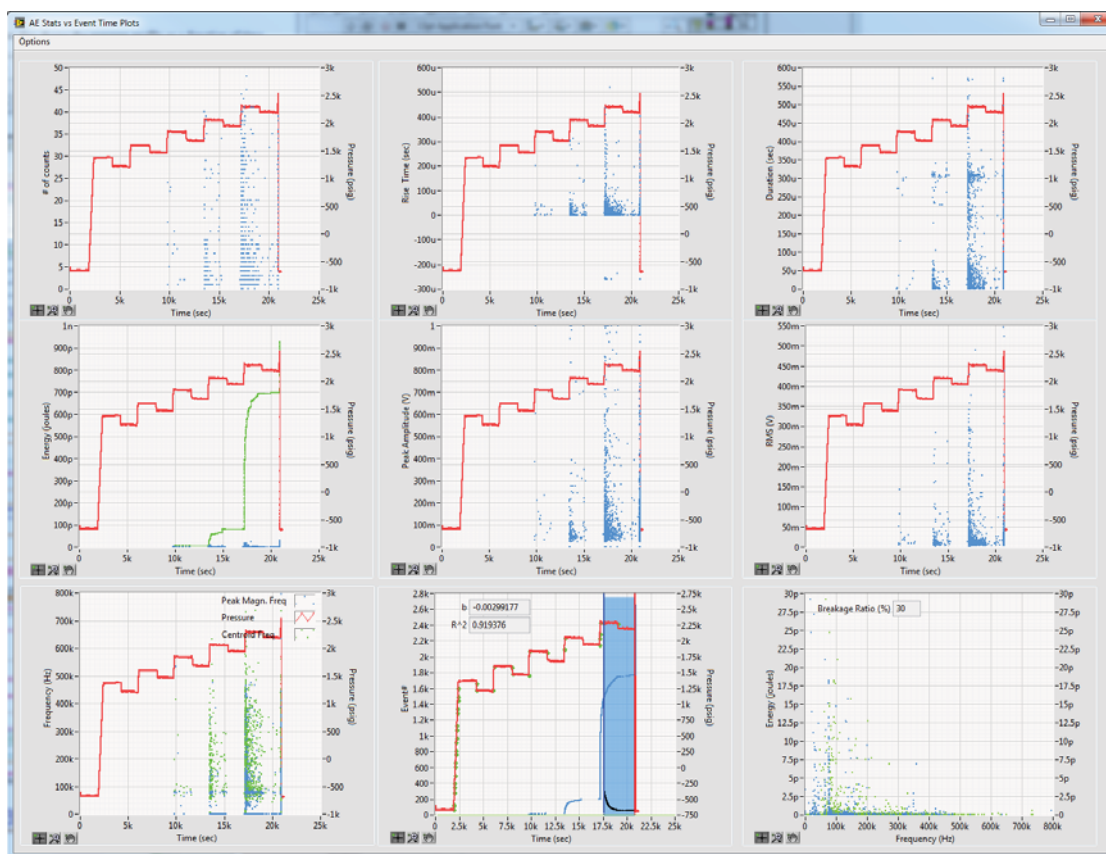


Figure 8.—AE statistics versus time and pressure window.

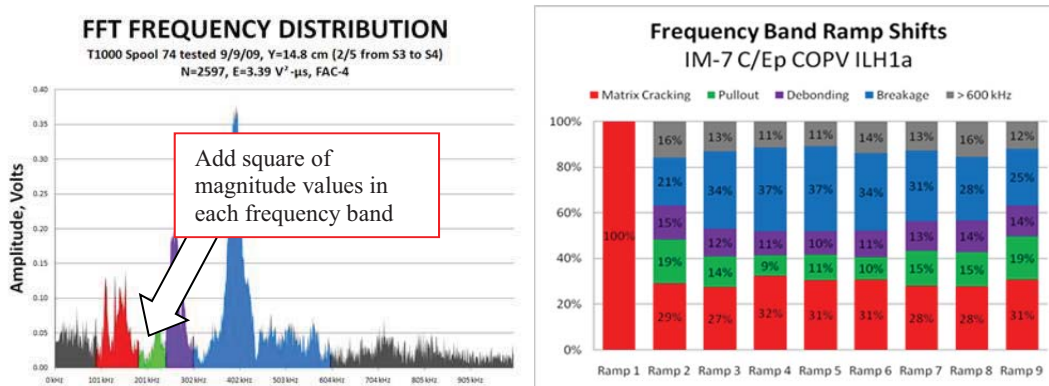


Figure 9.—Partial powers analysis showing correlation of damage mechanisms with time/ramp number and frequency. Color codings indicate the material mechanism responsible for acoustic emissions at the various ramp periods and frequencies.

System Requirements to install and run AEAA executable include:

- PC running Win7 64-bit OS (version is available also for Win7 32-bit OS).
- 1 GHz or faster processor.
- 4 GB RAM.
- Minimum 100 GB Hard Drive Space but will depend on typical AE data file size processed.
- National Instruments LabVIEW 2011 64-bit run-time engine (RTE). Included with Installer.
- Unlike NDEWIP and CT-CURS, this software executable requires no license of any kind.

A summary description of the AEAA software is available at:

http://www.grc.nasa.gov/WWW/OptInstr/NDE_Acoustic_Emission_Software.html and the software is downloadable at <https://sr.grc.nasa.gov/public/project/88/>.

Conclusions

NASA Glenn Research Center has developed several pieces of important NDE-related software for different projects in the last 10 years. These software packages have proven critical in achieving milestones in NASA projects. The software has been made available to US entities via the NASA Technology Transfer and Partnership Office server (<https://sr.grc.nasa.gov/>). This article has provided brief overviews of the software packages' capabilities and requirements.

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Appendix A.—Software Architecture and User Interface Strategy

Software Architecture

All three software programs were coded in their current versions using LabVIEW 2010 and 2011 and associated toolkits (Vision and Advanced Signal Processing toolkits) as needed. Both 32- and 64-bit versions are available for Windows operating systems. LabVIEW (short for Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language from National Instruments. Primarily a tool for instrument control and data acquisition, LabVIEW has extremely powerful capabilities for signal and image processing and analysis. A top-down approach to design was developed for these software programs that included the sequential elements of system requirements, software requirements, architectural design, detailed design, coding, testing, and maintenance. The software architecture is based on either a one- or two- loop producer-consumer event-driven state machine architecture in which Graphical User Interface (GUI) events such as menu selections are first sensed in a producer loop, and then executed in a consumer loop (two loop architecture) or separate case structure (one loop architecture). Figure 10 shows a simple two loop producer-consumer event-driven state machine.

Action items that need to be executed as a result of the GUI action are placed in a queue in the proper execution order in the producer loop. The action items are stored in an enumerated type definition control which is easy to add or delete items from. The producer loop consists of an ‘event structure’ inside of a ‘while loop’. The queue is unloaded in the proper order in a separate consumer loop that processes the needed actions. The consumer loop consists of a ‘case structure’ inside of ‘while loop’ with cases for all the actions that need to be executed.

Other background items are monitored and processed in additional loops outside of the main producer-consumer loop structure. This architecture facilitates debugging of code and in general provides for easier maintainability and upgradability. For subroutine (subVI) code modules that execute a smaller set of specific tasks, a single loop event-driven state machine is used in which GUI events and execution events occupy the same loop and are directed to the appropriate case structures.

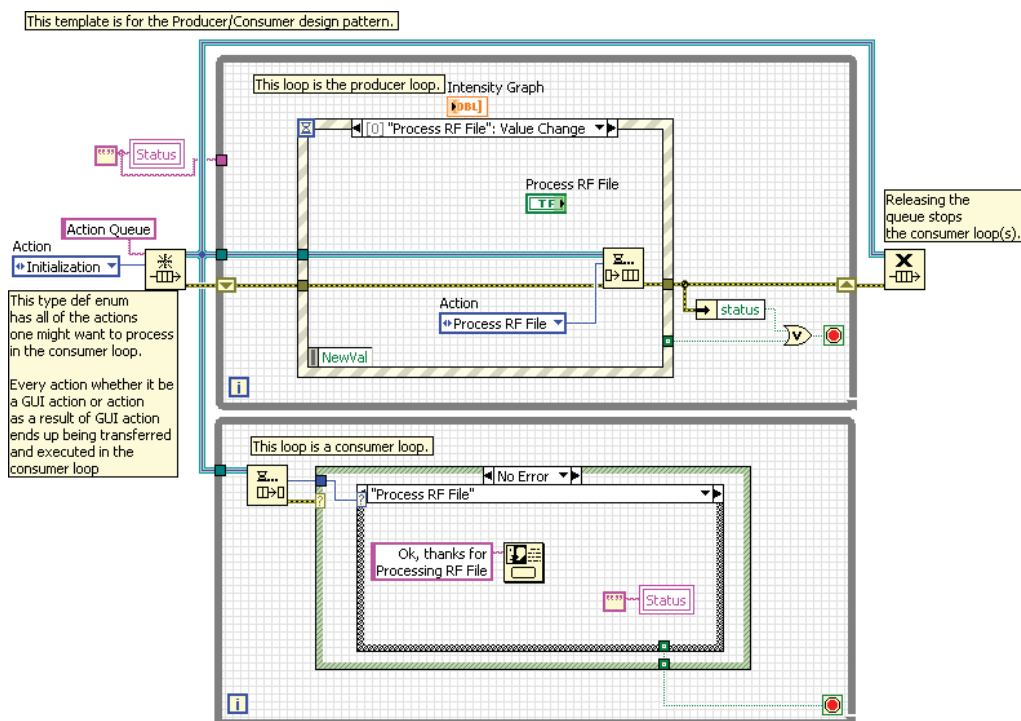


Figure 10.—Producer-consumer software architecture in LabVIEW.

User Interface Strategy

All three software programs use custom run-time menus, strategic front panel interface controls, and status indicators on the front panels to facilitate usability, with an example shown in Figure 11. The use of run-time menus presents the user with main categories under which logically organized submenus of action items can be hidden as shown in Figure 12.

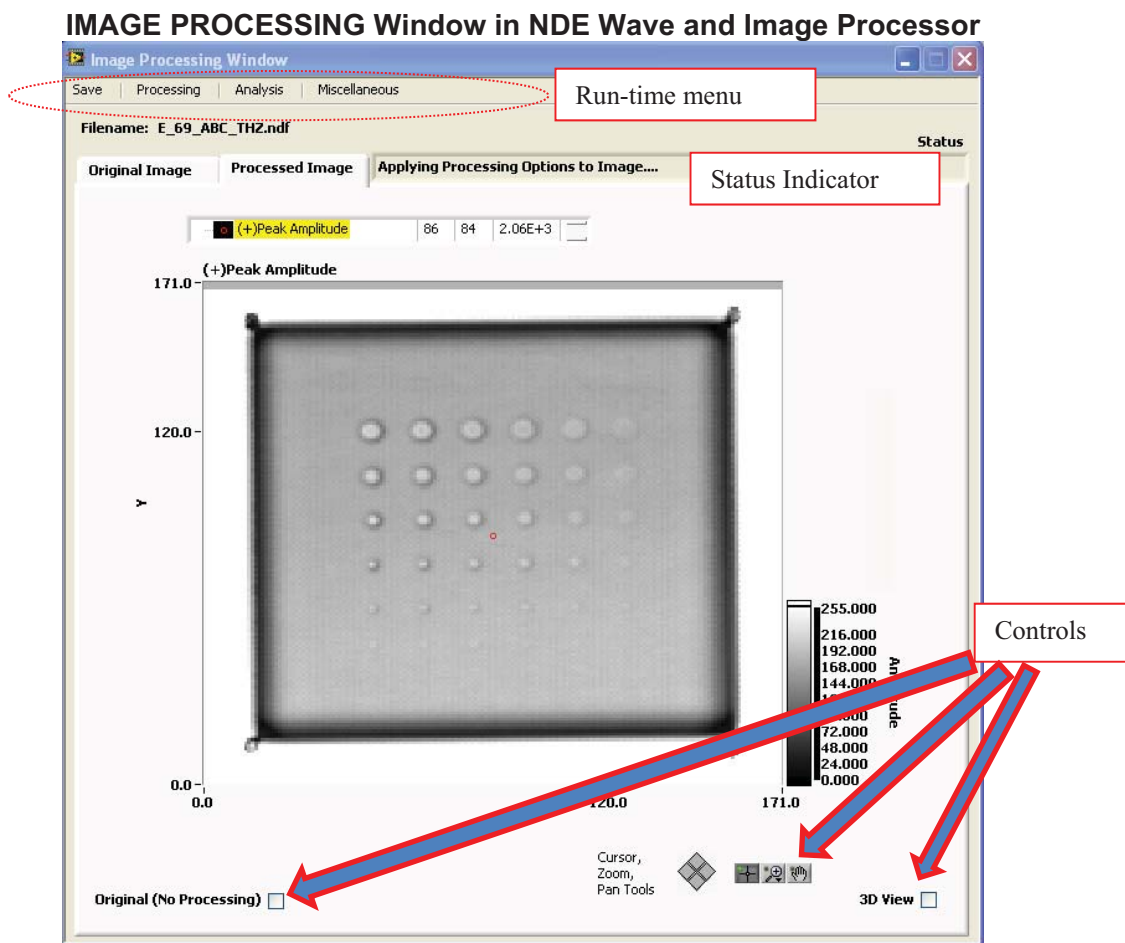


Figure 11.—Example of user interface strategy.

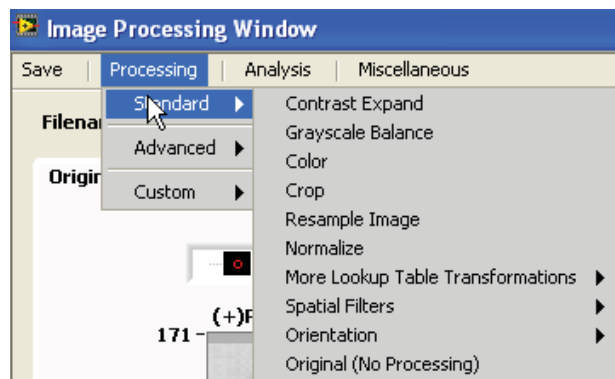


Figure 12.—Mouse clicking typical run-time menu item open sub-menus.

Appendix B.—NDF File Format for Waveform Data

All numerics are written as Little Endian. Data type designations are as follows:

- Integer = 16-bit/2-byte integer
- Long = 32-bit/4-byte integer
- Single = 32-bit/4-byte floating point number
- Double = 64-bit/8-byte floating point number
- String = ASCII character string

The header occupies byte positions 0 – 2047 in the file and is 2048 bytes in length. All strings are preceded by a 16-bit integer that indicates the string length. The waveforms are written beginning at file position 2048 (referenced to 0). Each waveform is 2048 positions with each position represented in Integer (2 byte) format. The amplitude at each of the 2048 positions is scaled to between –32768 and +32767 based on the acquisition voltage range with the range minimum voltage corresponding to –32768 and the range maximum voltage corresponding to +32767. The waveforms are stored sequentially with the scan proceeding from left to right (scan axis or X axis) and from bottom to top (increment axis or Y axis) (scan start location is lower left-hand corner). Currently, the software requires scan units to be in cm or inches. The number of datapoints per waveform can be any length. It is suggested to limit the length to maximum of 4096 in order to reduce overall scan data set memory footprint. It is recommended that scan data set size should be at most 400 MB. The acquisition device gain setting is for informational purposes only and is here just to be consistent with the format for NASA LaRC terahertz data. The lower and upper acquisition range information is used to properly scale the data. If the acquisition device gain setting is not known or is not one listed below in the example values, just use 0.

TABLE 1.—HEADER FORMAT SPECIFICATION FOR NDF FORMAT

Field	Description	Example value
File revision as long	860243022	860243022
Header size as long	2048	2048
Data type as long	4	4
Scan units string length as integer	Gives the length of string describing scan units	4 or 10 (depending on whether “inch” or “centimeter”).
Scan units as string	Contains either “inch” or “centimeter”	Either “inch” or “centimeter”
Acquisition device string length as integer	Gives the length of string describing acquisition device	e.g., 24
Acquisition device as string	ID string from DAQ card or acquisition device	e.g., QA-1000 with Spinner Mod
Data points as long	Data points per waveform	e.g., 2048
Sample rate as single	Sample rate of acquisition device (Hz)	e.g., 6.4×10^{12}
Scan axis string length as integer	Gives the length of string describing scan axis	1
Scan axis as string	Horizontal or vertical B-scan	=A if horizontal B-scan (=B if vertical B-scan)
Scan axis points as long	Number of scan axis points	e.g., 171
Scan axis resolution as double	Scan axis dimension measurement interval	e.g., 0.1
Scan axis size as double	Scan axis points x scan axis Resolution	e.g., 17
Incr axis string length as integer	Gives the length of string describing increment axis	1
Incr axis as string	Horizontal or vertical B-scan	=B if horizontal B-scan (=A if vertical B-scan)

TABLE 1.—Concluded.

Field	Description	Example value
Incr axis points as long	Number of increment axis points	e.g., 169
Incr axis resolution as double	Increment axis dimension measurement interval	e.g., 0.1
Incr axis size as double	Increment axis points x increment axis resolution	e.g., 16.8
Total scan points as long	Scan axis points X increment axis points	e.g., 28899
Acquisition device gain as long	Gives voltage range for acquisition	$-1 = \pm 10 \text{ V}$, $1 = \pm 5 \text{ V}$, $10 = \pm 0.5 \text{ V}$, 0 = unknown
Acquisition program info. string length as integer	Gives the length of string describing acquisition program info.	e.g., 24
Acquisition program info. as string	Fill in with scan version number ' app. major app. minor app. revision	e.g., SOFI Scan Version 4.1.32
Acquisition range lower as single	Gives lower voltage range for acquisition (V)	e.g., -10
Acquisition range upper as single	Gives upper voltage range for acquisition (V)	e.g., 10

